ARMY RESEARCH LABORATORY

Characterization of Particle Output From a Percussion Primer

by Lang-Mann Chang and Anthony W. Williams

ARL-TR-4188 **August 2007**

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

ARL-TR-4188 **August 2007**

Characterization of Particle Output From a Percussion Primer

Lang-Mann Chang and Anthony W. Williams
Weapons and Materials Research Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
August 2007	Final	15 January 2006–1 December 2006

4. TITLE AND SUBTITLE
Characterization of Particle Output From a Percussion Primer

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Lang-Mann Chang and Anthony W. Williams

5d. PROJECT NUMBER
622618.H8099

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRD-ARL-WM-BD
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-4188

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Measurements were made for the percentage of combustion products in condensed phases from a no. 41 percussion primer, and the influence of the condensed phases on the charge ignition in the 5.56-mm ammunition was characterized. The studies were carried out in three phases using three different test fixtures. Results showed 34% of the combustion products in condensed phases, including liquid and solid particles. With the residue remaining in the primer cup added together, the percentage increased to 44%. Subsequently, a channel was developed that was able to capture most of the particles exiting from the primer. Tests were then conducted for primer output flows, with and without particles present, interacting with propellant in a closed chamber. The pressure-time traces for the two flow conditions closely followed each other during the early period of time. At a later time, however, the pressure rise became much faster for the flow with particles present. A correlation of the pressure measurement to photographic evidence suggested that the condensed phases may have helped accelerate the charge ignition process and possibly reduced the ballistic cycle time but had no significant influence on the initiation of charge ignition at the ambient temperature of 21 ^{o}C. Further studies will be required to examine the results at cold temperature conditions.

15. SUBJECT TERMS
percussion primer, no. 41 primer, particles, charge ignition

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL	24	Lang-Mann Chang
					19b. TELEPHONE NUMBER *(Include area code)* (410) 278-6692

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction

The no. 41 primer has been used for decades to provide the ignition stimulus for 5.56-mm ammunition. Nevertheless, little has been documented or understood about the physical properties of the primer combustion products and how they interact with the propellant in the cartridge. These details of the primer performance have become vitally important given the Army's recent interest in the investigation of possible small-caliber replacements, which are environmentally friendly. As a result, considerable effort including modeling and experimental work has commenced. The modeling effort has focused specifically on the development of a primer model which captures the gas and solid particle output. On the other hand, the experimental work is intended to investigate the combustion products and the flow characteristics of the primer output. The results of the experiments will be extremely valuable in understanding how the primer works as well as in validation of the modeling. Once the modeling capability is established, alternative and improved propulsion systems, including primers and charges, can be studied and compared more efficiently.

As to characterization of primers for small-caliber ammunition, Kuo et al.[1] measured and compared the mass flow rates from three different primers—namely, FA-41 (i.e., no. 41), FA-34, and CCI-200. They also used flow equations and a thermochemistry program to compute the mass flow rates. The results indicate that the entire time duration required for the FA-41 primer to consume completely is in the range of 100 μs. Furthermore, their computations show that the percentage of the condensed phases (solid and liquid) in the combustion products is in the range of 40%. Finally, the studies suggest that multiphase flow considerations for primer characterization studies are essential.

Recently, Williams et al.[2] conducted experimental studies with the no. 41 primer firing in the open air and then in a closed chamber resembling the cartridge geometry and volume of the 5.56-mm ammunition. Three chamber conditions were considered—empty, filled with inert grains, and packed with live propellant. Images from high-speed videos show evidence of fine particles appearing in the early time of primer output (see figure 1). Large particles then appeared later in the firing event. In the study, a witness plate with a carbon tape on the surface was opposite of the primer exit flow to capture particles accompanying the gaseous flow. Figure 2 shows typical images of the particle distributions on the tape located 66.5 and 123.5 mm from the primer, respectively. Analyses were performed with the particles for their

[1] Kuo, K. K.; Moore, B.; Chen, D. *Characterization of Mass Flow Rates for Various Percussion Primers, Gasdynamics of Detonations and Explosives*; AIAA Progress Series; Vol. 75, pp 323–337, 1981.

[2] Williams, A. W.; Brant, A. L.; Kaste, P. J.; Colburn, J. W. *Experimental Studies of the No. 41 Primer and Ignition of 5.56-mm Ammunition*; ARL-TR-3922; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, September 2006.

1st Light Time = 0.0 | Time = 135 μs | Time = 810 μs

Figure 1. Flame development from no. 41 primer in open air (*2*).

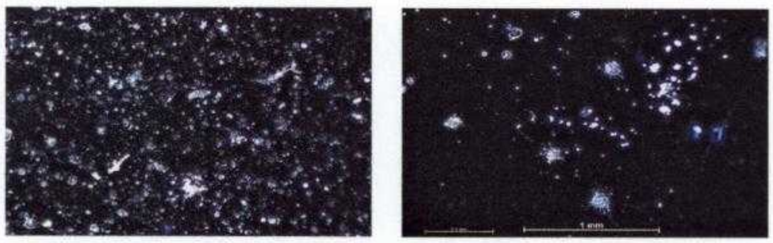

Figure 2. Particles on carbon tape witness plates located 66.5 mm (left) and 123.5 mm (right) from primer (magnified) [*2*].

compositions. Some of the field emission-scanning electron microscopy (FE-SEM) images (150–2500× magnification) of these particles in different shapes are displayed in figures 3–5. The particle shown in figure 3 did not melt during the combustion process, and the energy dispersive spectroscopy (EDS) analysis indicates that the particle consists primarily of barium (Ba). It is noted that the chemical composition of the primer mixture is lead styphnate (37% by weight), barium nitrate (32%), antimony sulfide (15%), aluminum powder (0.7%), tetracene (0.4%), and PETN (0.5%). The particle presented in figure 4 was coated with many tiny aluminum (Al) particles and probably did not melt. It contains mainly Sb (antimony) and S (sulfur), with the presence of Ba. Figure 5 shows a dispersed particle, which apparently melted when it hit and splattered. This particle contains Ba, with the presence of Sb and S.

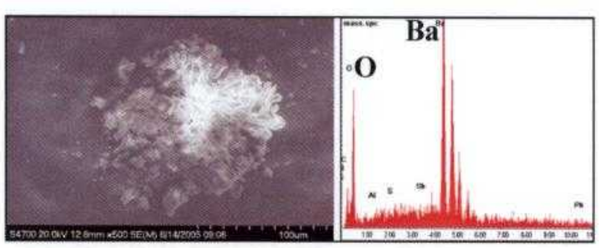

Figure 3. EDS spectrum of some representative particles (*2*); particle apparently did not melt, consists mainly of Ba.

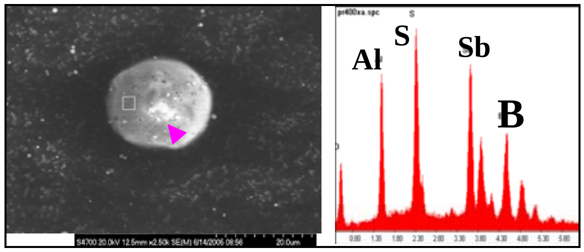

Figure 4. EDS spectrum of some representative particles (*2*); particle apparently did not melt, consists mainly of Sb and S.

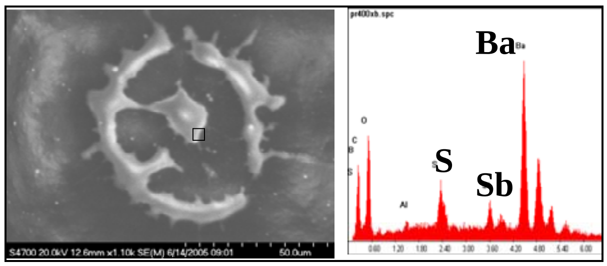

Figure 5. EDS spectrum of some representative particles (2); melted particle, captured while apparently in the process of dispersing, consists mainly of Ba, Sb, and S.

As part of the overall effort, Schmidt and Nusca[3] have made significant progress in developing a multiphase turbulent model of the gas/particle flow in the channel connecting the primer to the propellant-filled cartridge. The primary purpose of this work is to develop a primer model to serve as an input to the U.S. Army Research Laboratory (ARL)-NGEN3 IB code.[4,5] Once the primer code becomes available, the IB code will be employed to predict the interior ballistic cycle.

The present study, an integral part of the experimental work, focuses on two areas. One is to quantitatively determine the mass percentage of the condensed phases in the combustion products of the no. 41 primer, and the other is to characterize the effect of the condensed phases on charge ignition.

---

[3] Schmidt, J. R.; Nusca, M. J. *Progress in the Development of a Multiphase Turbulent Model of the Gas/Particle Flow in a Small-Caliber Ammunition Primer*; ARL-TR-3860; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 2006.

[4] Gough, P. S. Modeling Arbitrarily Packed Multi-Increment Solid Propellant Charges of Various Propellant Configurations. *Proceedings of the 33rd JANNAF Combustion Meeting*, CPIA Publication 653, November 1996; Vol. I, pp 421–435.

[5] Nusca, M. J. *Numerical Model of Multiphase Flows Applied to Solid Propellant Combustion in Gun Systems*; AIAA Paper No. 98-3695, July 1998.

2. Experimental Setup

Tests in the present experimental effort proceeded in three phases using three different test fixtures. The first phase is designed to determine the mass of the combustion products in condensed phases produced by the no. 41 primer. The constituents contained in the primer include neat primer material, a thin paper seal, and lacquer. The purpose of the second phase is to condition the flow exiting from the primer and minimize the presence of the condensed phases.

The third-phase experiments provide a direct comparison of charge ignition initiated from a flow with and without the presence of a significant amount of condensed phases. It is noted that in the following discussion, "particles" and "condensed phases" will be used alternately wherever appropriate.

2.1 Phase I Tests

Figure 6 shows the test fixture used to determine the mass of the combustion products in condensed phases. The chamber depicted in the figure, made of Lexan, is 7.9 mm in diameter and 35.6 mm in length, giving a volume approximately the same as that in the cartridge of the 5.56-mm ammunition. The lower end of the chamber is completely sealed, and the upper end has a small opening adapted to the nozzle exit of the primer holder. The chamber is firmly held between two rectangular steel plates.

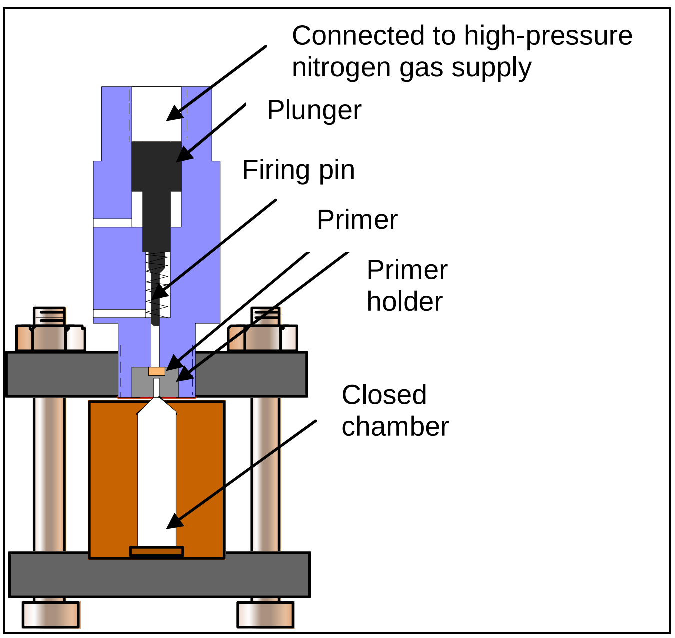

Figure 6. Test fixture for measuring mass of condensed phases (i.e., particles).

In operation, the primer is initiated by an impact from a striking pin attached to the forward end of the plunger (see figure 6). The plunger is driven by a high-pressure pulse generated from a sudden release of nitrogen gas from a 1000-psi nitrogen tank through a flexible tubing (6.35-mm diameter). A solenoid valve, activated by a power supply of 12 V, is employed to release the necessary pressure pulse. Furthermore, a pressure regulator is installed in the up stream of the valve to regulate the gas pressure to 750 psi, which is adequate to initiate the primer.

Prior to and after each test run, the chamber, primer, and primer holder are carefully weighed using a digital scale (Denver Instrument Company, A-160), which has an accuracy of 0.1 mg. The measured increase of the chamber mass postfiring represents the total mass of the combustion products in condensed phases. These products are expected to reach the propellant bed in the small ammunition in gun firing. The amount of residue remaining inside the primer cup/anvil assembly is also weighed and recorded. It should be noted that the products and/or residue may include an unknown contribution from the previously mentioned sealing paper.

2.2 Phase II Tests

Figure 7 depicts the test fixture designed to capture the condensed phases (i.e., particles). The overall assembly and operation are essentially the same as that just described for the phase 1 experiment except that the chamber is replaced with a Lexan block having a flow channel inside. The block is actually composed of two pieces bonded together, and the flow channel is machined into one of the pieces. The channel has a square-shaped cross section (4.7 mm × 4.7 mm) rather than circular shape, simply because it is easier to machine. The shape of the channel crosssection is not important for the present tests. The upper end of the channel is connected to the exit end of the nozzle in the primer holder, and its lower end is open to the ambient air.

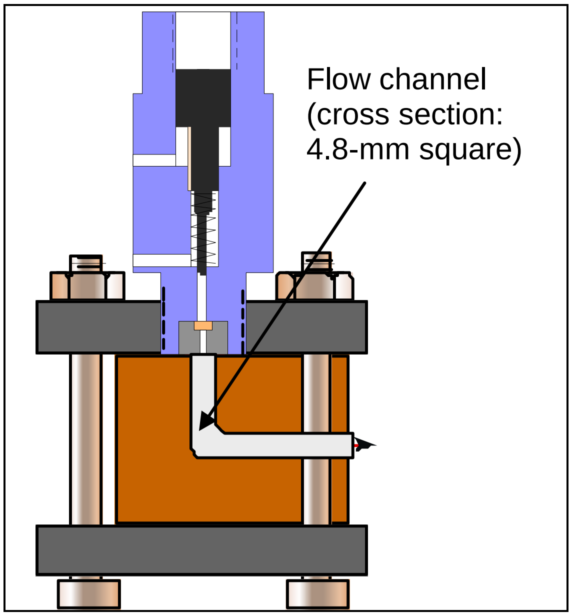

Figure 7. Test fixture for capturing particles.

There are two sets of tests to be conducted using this test fixture. The first set of tests is designed to allow the flow from the primer to carry particles all the way to the channel exit. The second set of tests will have most, if not all, of the particles captured before the flow exits the channel. In order to capture the particles, without significantly disturbing the flow pattern, the channel walls are lined with a 0.0127-mm-thick polyester film having 0.0445 mm of acrylic adhesive on each side (double-sided tape). During the test series, it was determined that the effectiveness of capturing particles (removing them from the flow) is extremely sensitive to the radius of curvature at the turn in the channel. A variety of radii of curvature was tested before reaching the final configuration shown in figure 7. Using the final configuration was the flow exiting the channel may or may not contain a large number of particles, depending on whether or not the channel walls were lined with adhesive. The effectiveness of removing particles from the flow in this test series (phase II) will ensure the validity of the subsequent test series (phase III).

A Phantom V7 digital camera has been employed extensively to provide high-speed photography of the flow exiting from the channel. Based on the images recorded, the presence of particles in the flow can be quantified. A camera setting of 15,000 to 22,000 fps, with an exposure time of 15 μs, provides excellent images of the exiting gas and particle flow.

2.3 Phase III Tests

Figure 8 shows the test fixture used to evaluate the effect of particles on propellant ignition. The length of the Lexan block is extended to accommodate a long chamber with a volume comparable to the volume of the 5.56-mm cartridge. As seen in the figure, the chamber is partially packed with 0.3694 g of live WC844 propellant downloaded from an M855 cartridge. The remainder of the chamber volume is filled with 1.0845 g of inert grains. A piece of thin paper is placed between the inert and live propellant grains to keep them in a proper position. The paper separates the grains only prior to ignition; it will be consumed during firing. The test fixture is oriented so that the chamber stands vertically with the live propellant on the top to maintain the integrity of the propellant beds in the chamber.

A Kistler (Model 211B1) gage is installed in the entrance section of the chamber for pressure measurements. The gage is designed to accurately measure pressures up to 10,000 psi. Data were recorded at a 2-MHz sample rate.

3. Test Results and Discussion

3.1 Mass of Combustion Products in Condensed Phases

Five tests were performed at the ambient temperature of ~21 °C in the first test series. The closed chamber used to capture particles, the primer, and primer holder (shown in figure 6) were individually weighed immediately prior to each firing. These elements were weighed again

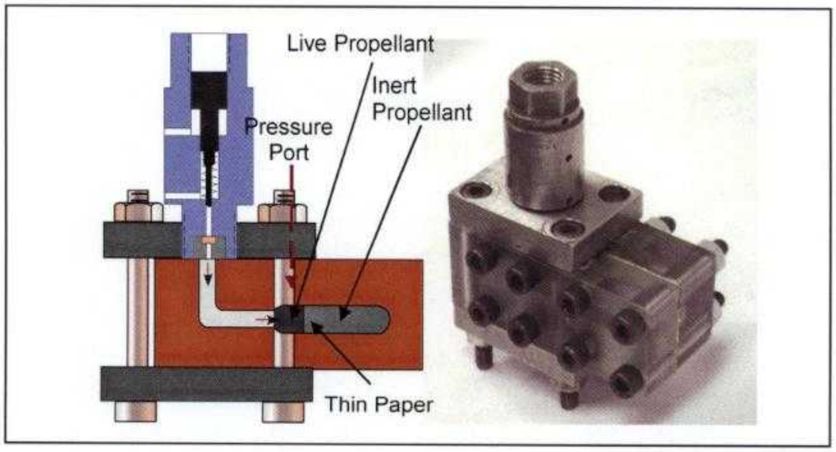

Figure 8. Test fixture for evaluation of effect of condensed phases on charge ignition.

immediately after firing to minimize possible moisture effects. There were some loose particles remaining inside the primer cup/anvil assembly, and a small amount of fine powder was attached to the exit end of the primer holder. The nozzle in the primer holder, which is made of steel and through which the primer vented into the closed chamber, had no measurable change in diameter throughout the tests, indicating no significant nozzle erosion occurred during the experiments.

The measured particle mass data are recorded in table 1. It is noted that each no. 41 primer weighs about 0.2136 g before firing. Of the mass, there is ~0.025 g of reactive material, together with its sealants, composed of a thin paper and lacquer.[2] The test results show that the primer combustion products in condensed phases recovered in the closed chamber is ~0.0085 g, which is 34% of the constituents originally filled in the primer cup. This amount of combustion products in condensed phases is expected to enter the charge system in firing a live 5.56-mm round. When the loose particles (figure 9) remaining in the primer cup and the primer holder are included, the total mass of the combustion products in condensed phases becomes 0.0110 g, which is 44% of the mass 0.025 g. The additional mass is recovered by tapping the primer vigorously. It is not known that 100% of the postfiring residue was removed from the primer, so this number (44%) represents a minimum mass recovered. This percentage is close to the 40% value predicted by Kuo et al.[1]

3.2 Effectiveness of Capturing Particles

The flow channel shown in figure 2 is longer than that between the primer and propellant bed in an actual round. However, the current test series is designed to evaluate the effectiveness of the adhesive tape in capturing particles, medium and large in particular, in the flow. The images of the flow exiting the channel recorded by a Phantom V7 high-speed digital camera furnish the evidence needed for the evaluation.

Table 1. Measured particle mass data.

Test No.		Prefiring (g)	Postfiring: Before Cleaning (g)	Postfiring: After Cleaning (g)	Particles (g)	Total Particles Produced (g)
1	Chamber	21.8794	21.8707		0.0087 (34.8%)	0.0113 (45.2%)
	Primer		0.2136	0.2116	0.0020	
	Primer Holder				0.0006	
2	Chamber	21.9375	21.9459		0.0084 (33.6%)	0.0108 (43.2%)
	Primer		0.2137	0.2119	0.0018	
	Primer Holder		3.1956	3.1950	0.0006	
3	Chamber	21.9380	21.9465		0.0085 (34%)	0.0110 (44%)
	Primer		0.2135	0.2113	0.0022	
	Primer Holder		3.1954	3.1951	0.0003	
4	Chamber	21.9254	21.9340		0.0086 (34.4%)	0.0111 (44.4%)
	Primer		0.2129	0.2109	0.0020	
	Primer Holder		3.1851	3.1845	0.0006	
5	Chamber	21.9123	21.9206		0.0083 (33.2%)	0.0106 (42.4%)
	Primer		0.2147	0.2129	0.0018	
	Primer Holder		3.1864	3.1859	0.0005	

Notes:
- Average particles in chamber: 0.0085 g = 34% of original constituents.
- Average total particles produced: 0.0110 g = 43.8% of original constituents.

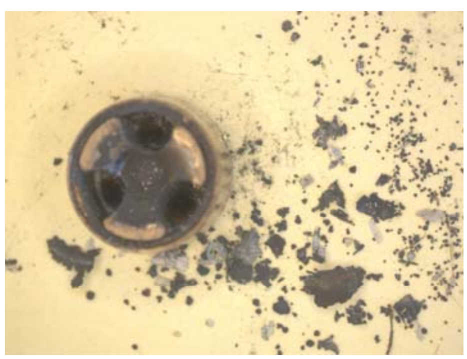

Figure 9. Residue remaining in primer after firing.

3.2.1 Particles in the Flow (Without Tape Lining the Channel Walls)

Figure 10 presents a series of images obtained from the high-speed camera showing the flow development from a channel without adhesive tape lining its walls. The framing rate is set at 15,037 fps, giving a time interval of 67 µs between two adjacent frames, and the exposure time is

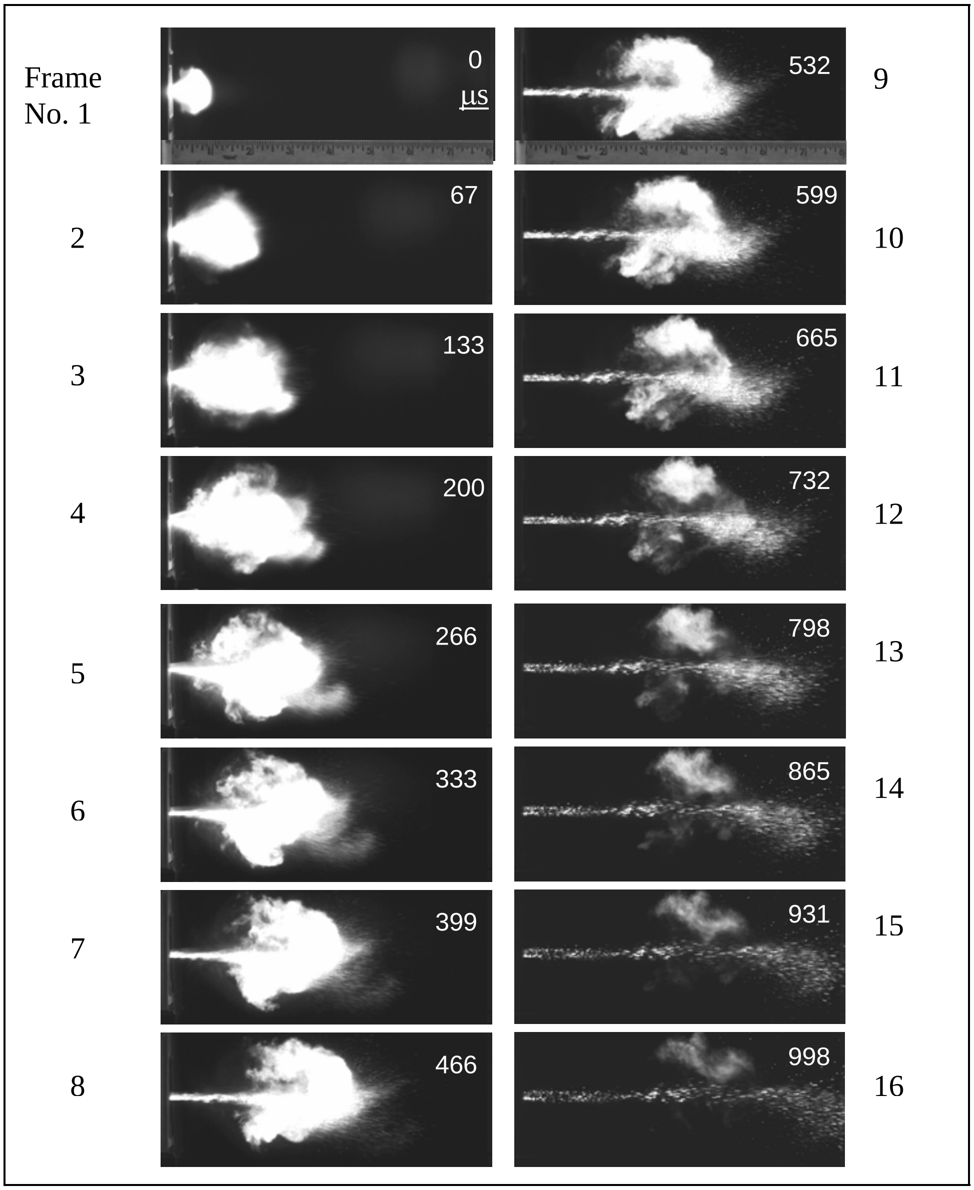

Figure 10. Flow development for channel without adhesive on channel walls (0 µs = the instant that the first visible light seen).

15 µs. As observed previously,[2] strong shock waves develop immediately as the flow exits the channel. Detailed flow structure, including a barrel shock, a normal shock, and a precursor shock, can be visualized when the camera setting is properly adjusted.

The time zero indicated in the figure is set at the instant the first visible light is seen. The precursor shock wave, at the leading edge, travels at an average speed of ~450 m/s between the first and the second frames. The speed decreases rapidly as the flow continuously expands into the still ambient air. It is interesting to note that from the third frame on, numerous streaks, which are the traces of moving fine particles, are seen in front of the gas flow. Apparently, this is due to the inertia force that brings the fine particles ahead of the decelerating gas flow. At a

later time (frame 6 or 7), more and more large particles are seen traveling ahead of the visible gas flow. From frame 11 and later, a large stream of particles spreads over the entire range of the visible flow region. Many of these particles are still visible after 1000 µs. The primer output time is apparently much longer than 100 µs, as observed by Kuo et al.[1]; perhaps this is due to the fact that a large flow chamber was added in front of the primer in their test fixture. Some of the particles observed in figure 10 appear quite large. The photographic evidence reported previously[2] reveals that particles in liquid phase are also present.

These observations reveal an important fact that numerous fine particles exit the channel (thus, from the primer) from the very beginning of primer output and then medium and large particles at a later time, possibly after 300 µs.

3.2.2 Particles Removed From the Flow (With Tape Lining the Channel Walls)

Figure 11 depicts the video images of the flow exiting a channel that is lined with an adhesive tape. The camera settings in this test are identical to those in the previous experiment. For a channel not lined with an adhesive tape, the flow development shown in the first four frames is fairly similar to that seen in figure 10. From frame 5 on, however, the flow pattern changes significantly. There are no longer a large number of medium and large particles appearing in the flow. Figure 12 gives a direct comparison of the respective flow fields at 798 µs after the first visible light appears. The video evidence clearly indicates that the addition of adhesive tape captures the vast majority of the medium- and large-sized particles.

In figure 11 (as also seen in figure 10), fine particles can be seen exiting the channel at nearly the same speed of the gas (closely note the third and the subsequent frames). A close comparison of the flow fields indicates that with the same camera setting, the light intensity of the flow field in figure 11 is relatively lower than that shown in figure 10. This can be attributed to the absence of medium and large particles in the flow field.

3.3 Particle Effect on Charge Ignition

Figure 13 presents the pressure-time traces recorded in the entrance section of the chamber (figure 6) for flows with and without particles present. Here, “without particles” includes “only a few medium and large particles.” In the recording, the oscilloscope is triggered by a pressure set at 2 MPa rather than by the solenoid or other means, which will be discussed later. Therefore, in the figure, “0 µs” is the instant that the trigger occurred. The two pressure-time traces are plotted to have a common pressure of 2 MPa at 0 µs. The pressure-time curves match very closely until 1 µs on the time coordinate. The pressure rise during this early time period is, in fact, solely the result of the primer output. After 1 µs, the pressure for the primer flow with particles rises more rapidly in comparison with pressure produced without particles present. The peak pressure (with particles) is also higher. After the peak pressure is reached, the pressure falls quickly due to heat loss and a minor leak occurring around the chamber area when the pressure

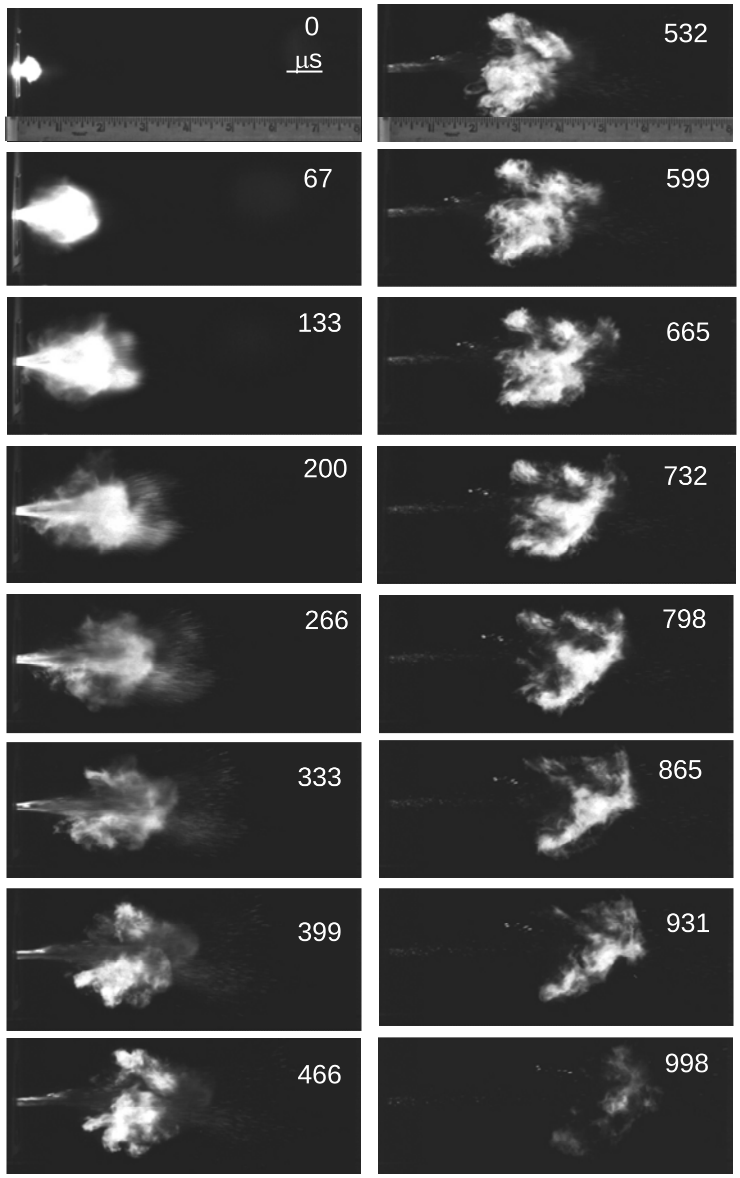

Figure 11. Flow development for channel with adhesive on channel walls.

becomes very high. This leakage does not affect the early pressure rise. Under the current channel conditions, the presence of particles is demonstrated to have a significant contribution to the quickness of the pressure rise.

It would also be interesting to examine the role of the condensed phases in charge ignition delay. To date, a method for accurate and reliable measurements of charge ignition delay in small-caliber ammunition has not been well established because of the difficulty in determining the necessary time basis for the measurement. Using the instant that the solenoid is activated as the time basis is generally not reliable because of inconsistency in the activation time.

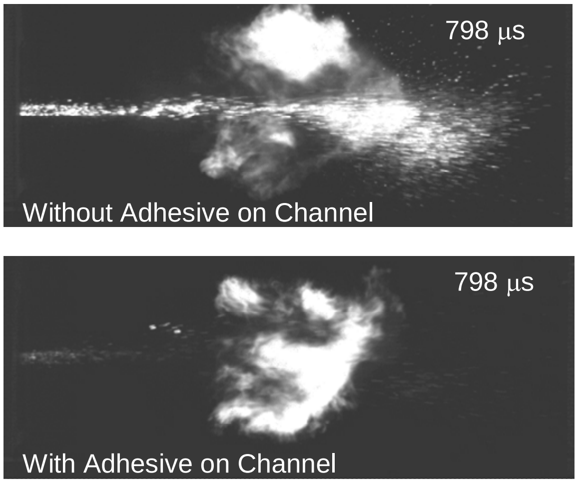

Figure 12. A direct comparison of flow fields at 798 μs.

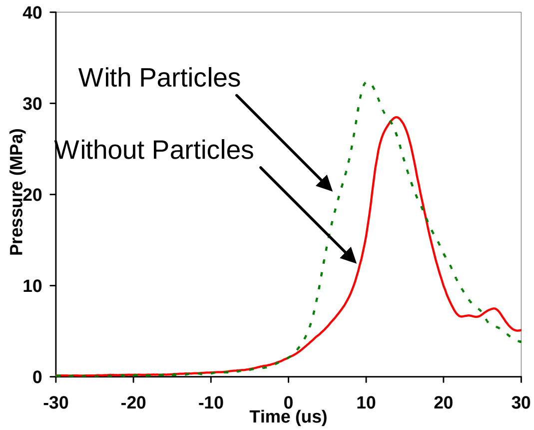

Figure 13. Pressure-time traces in propellant-packed chamber for flows with and without particles present.

The method of using the instant that the striking pin impacts the percussion primer as the time basis has been attempted. However, results from test runs reveal that there is a significant variation in the time interval from the impact to the flow first exiting the channel from round to round. To determine the ignition delay, one may propose to use the pressure-time trace recorded in the cartridge chamber in gun firings. However, the available measurements are obtained by triggering the data acquisition system from the pressure while saving enough data prior to the trigger time to ensure the entire pressure curve is recorded. Again, the time basis is not well defined. Additionally, it is also difficult to determine the exact point along the pressure-time trace at which charge ignition occurs. A breaking conductive wire or strip placed across the nozzle exit of the primer holder or simply a diode installed near the nozzle exit could be an option.

In spite of the difficulty to accurately determine the ignition delay, the images given in figure 14 do provide sufficient information for the present interest of characterizing the ignition effect of the condensed phases. The images show the flame propagation with particles present (no adhesive on the channel walls) from a no. 41 primer to a closed chamber filled with live propellant in the entrance section and inert grains in the remaining volume. In the test, the high-speed camera was set at a framing rate of 66,666 fps, giving a time interval of 15 μs from one frame to the next. Therefore, the accuracy of the time measurement is within 15 μs. As in figures 10 and 11, "0 μs" is defined as the instant that the first visible light is seen. Following the flame propagation, it is estimated to be 30 μs for the flame to reach the propellant bed. After penetrating into the propellant bed, the flame nearly died out at about 100 μs. Light then reappeared in the entrance section of the chamber shortly after 105 μs. This light was apparently generated from propellant ignition. Thus, the flame development suggests that propellant ignition occurred within 120 μs after the first visible light appeared at the nozzle exit of the primer holder. Subtracting the time for the flow to travel through the channel, which is about 30 μs, the time interval reduces to less than 90 μs at which charge ignition should have begun in an actual 5.56-mm round. In figure 10, by the time 90 μs have elapsed, medium and large particles have not yet appeared, or at least not in a large number. Therefore, the particles which appear later (i.e., after 90 μs) have no significant contribution to the initiation of charge ignition in this test configuration. However, in light of a faster pressure rise occurring after 1 μs (figure 13), the presence of particles does enhance charge ignition and therefore possibly reduces the time required to complete a ballistic cycle. It is noted that at cold temperatures, the ignition delay of the propellant is usually longer. Under this condition, particles may play an important role in reducing the ignition delay.

Fine particles (possibly burning and hot) exiting from the primer during the very early time may have a significant contribution to effective charge ignition. The particles carry kinetic energy that is transferred into heat energy upon impact with the propellant surface. The particles can also adhere to the propellant surface and promote high rates of conductive heat transfer to the propellant.

4. Summary

Tests were conducted in three test phases to measure the mass percentage of primer combustion products in condensed phases and to characterize their effect on charge ignition. In phase I, five tests were performed. The results showed that a minimum average percentage of 34% of the combustion products is in condensed phases. These products entered the charge system in the 5.56-mm ammunition. When including the residue recovered from the postfire primer, the

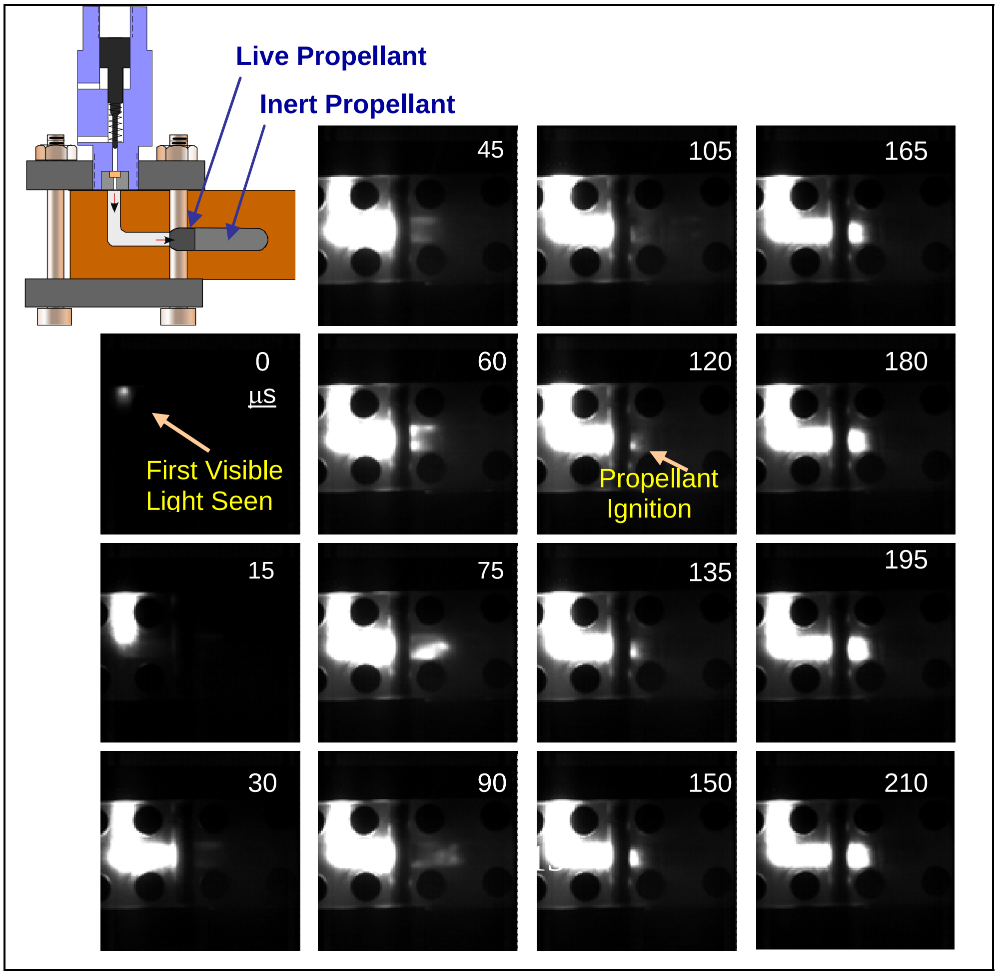

Figure 14. Flame propagation in channel and ignition of propellant (with particles in flow).

percentage increased to a minimum of 44%. It was noted that this is a minimum because it was unclear whether all of the primer residue was recovered. Also, although it was a very small portion of the total, the mass of the paper was unknown.

In phase II tests, a specially-configured channel was connected to the primer exit nozzle. The channel was used to produce a flow with or without particles, depending on whether or not the channel walls were lined with adhesive tape. Images from high-speed photography revealed that during the early time period, numerous fine particles were accompanying the primer gases exiting the channel either with or without adhesive on the channel walls. Later, a large stream of particles (medium and large size) appeared only in the flow from the channel, without adhesive on the channel walls.

Tests in phase III were conducted with a small closed chamber loaded with live WC844 propellant. The pressure rises in the entrance section of the chamber for the two flow conditions (with and without particles present) were monitored and compared. Analysis based on the pressure and photographic data suggested that the presence of condensed phases did not

significantly influence the initiation of the charge. However, it may have helped accelerate the charge ignition process and possibly reduce the time needed to complete a ballistic cycle. At cold temperatures, the contribution to propellant ignition could be appreciable but will not be investigated.

Fine particles (possibly burning and hot) exiting from the primer during the very early time may have a significant contribution to effective charge ignition.

A remark should be made that for a given mass of constituents, a primer without producing a large number of particles may have a stronger gas flow and thus may achieve similar ignition enhancement as achieved by condensed phases. A further investigation on this is needed.

NO. OF COPIES	ORGANIZATION
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	US ARMY RSRCH DEV & ENGRG CMD SYSTEMS OF SYSTEMS INTEGRATION AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC IMS 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK TL 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	DIR USARL AMSRD ARL CI OK TP (BLDG 4600)

NO. OF COPIES	ORGANIZATION
1	AMMO SYS PROJECT MGR MANEUVER SFAE AMO MAS SMC R KOWALSKI BLDG 354 PICATINNY ARSENAL NJ 07806-5000
2	ATK C AAKHUS M JANTSCHER MN07-LW54 4700 NATHAN LN N PLYMOUTH MN 55442
1	ATK LAKE CITY K ENLOW PO BOX 1000 INDEPENDENCE MO 64051-1000
1	ATK LAKE CITY SMALL CALIBER AMMO LAKE CITY ARMY AMMO PLANT D MANSFIELD PO BOX 1000 INDEPENDENCE MO 64051-1000
1	ATK LAKE CITY SMALL CALIBER AMMO J WESTBROOK MO10-003 PO BOX 1000 INDEPENDENCE MO 64051-1000
1	US ARMY TACOM ARDEC CCAC AMSTA AR CCL C G FLEMING BLDG 65N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC CCAC AMSTA AR CCL B J MIDDLETON BLDG 65N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC ASIC PROG INTEGRATION OFC J RESCH BLDG 1 PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	US ARMY TACOM ARDEC AMSRD AAR AEW M(D) M MINISI BLDG 65N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC S SPICKERT-FULTON BLDG 65N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEM T M NICOLICH BLDG 65S PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEM S MUSALLI BLDG 65S PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEM I R MAZESKI BLDG 61N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEM A A FARINA BLDG 95 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC CCAC AMSRD AAR AEM I D CONWAY BLDG 65N PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEM A H HUDGINS BLDG 95 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC CCAC AMSTA AR CCL D F HANZL BLDG 354 PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	APM SMALL & MEDIUM CALIBER AMMO SFAE AMO MAS SMC P RIGGS BLDG 354 PICATINNY ARSENAL NJ 07806-5000
1	OPM-MAS SFAE AMO MAS MC G DEROSA BLDG 354 PICATINNY ARSENAL NJ 07806-5000
1	ST MARKS POWDER GENERAL DYNAMICS R PULVER 7121 COASTAL HWY CRAWFORDVILLE FL 32327
1	ST MARKS POWDER GENERAL DYNAMICS J DRUMMOND 7121 COASTAL HWY CRAWFORDVILLE FL 32327
1	ST MARKS POWDER GENERAL DYNAMICS J HOWARD 7121 COASTAL HWY CRAWFORDVILLE FL 32327
1	RADFORD ARMY AMMO PLANT W WERRELL PO BOX 1 RT 114 RADFORD VA 24143

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
29	DIR USARL AMSRD ARL WM B M ZOLTOSKI AMSRD ARL WM BA D LYON AMSRD ARL WM BC M BUNDY J GARNER B GUIDOS K HEAVEY J NEWILL P PLOSTINS J SOUTH S SILTON D WEBB AMSRD ARL WM BD A BRANT (3 CPS) R BEYER L M CHANG (3 CPS) J COLBURN P CONROY N ELDREDGE B HOMAN S HOWARD P KASTE M NUSCA J SCHMIDT A WILLIAMS (3 CPS)